2012 Ocean Sciences Meeting, 20-24 February, Salt Lake City, Utah

Session # 016, Poster # B2067

Observations and High-Resolution Modeling of Small-Scale Flow-Topography Interactions Near Caribbean Coral Reefs

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ABSTRACT

Observations and a high-resolution (grid size of 50 m) 3D model are used for studies of the flow-topography interactions near coral reefs off the coast of Belize. Model results show that reefs with a unique shape of large horizontal curvatures and steep concave vertical slopes amplify current speeds and create internal wave-induced mixing and dispersion, providing a possible explanation why many species of Caribbean fish aggregate to spawn at these particular reefs. A case study of unusual observations of strong currents (over 1 m/s) and large water level changes (~0.7 m difference between two locations only 2 km apart) during a short-lived storm is simulated. The near-reef flow dynamics involve large-scale remote forcing from Caribbean eddies and tides, as well as small-scale local non-linear flow-topography interactions. The study has implications for submesoscale dynamics and the influence of external forcing on the biology and survival of coral reef communities.

Introduction

- The Mesoamerican Barrier Reef System in the western Caribbean Sea (Fig. 1a) provides spawning aggregation (Fig. 1d) sites for many species of Caribbean fishes. Those spawning aggregation reefs have similar unique geomorphology with large horizontal curvatures (Fig. 1b) and convex steep slopes.
- Flow-topography interactions involve a large range of spatial scales, from meso-scale Caribbean eddies and gyres of hundreds of kilometers to reef scale of a few kilometers, down to scales of meters, where intense mixing there help disperse larvae and eggs.
- Modeling approaches thus must include high resolution numerical models, observations and biological physical interactions.
- Potential forcing of the flow near the reef is not well understood and can include: >meso-scale eddies (Ezer et al., 2005) >wind >tides >internal waves (Ezer et al. 2011).

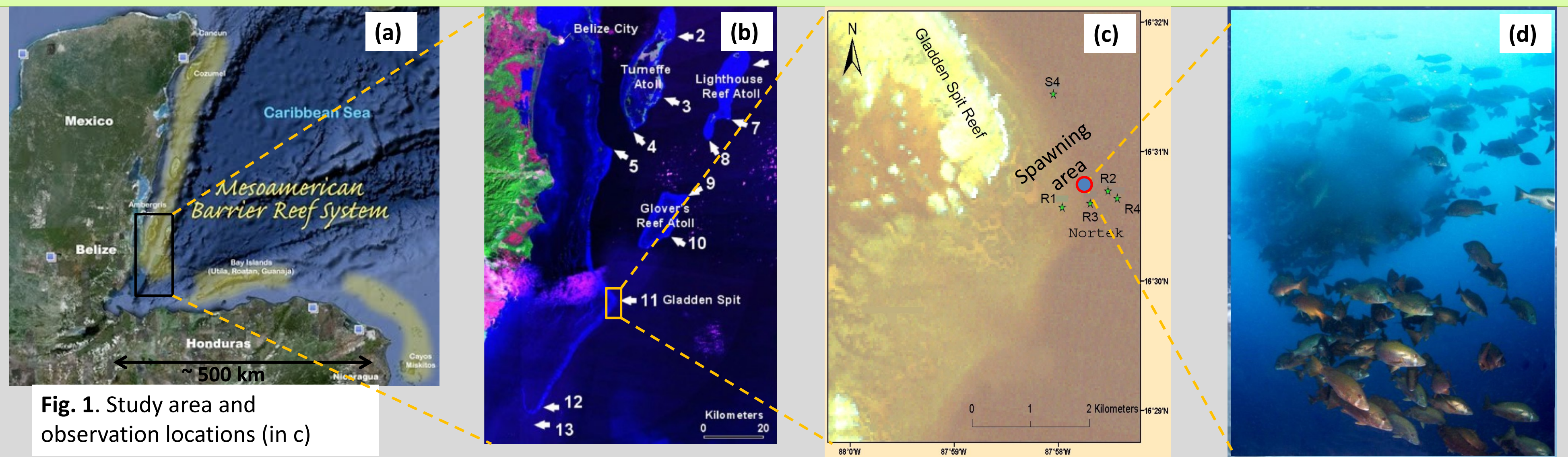
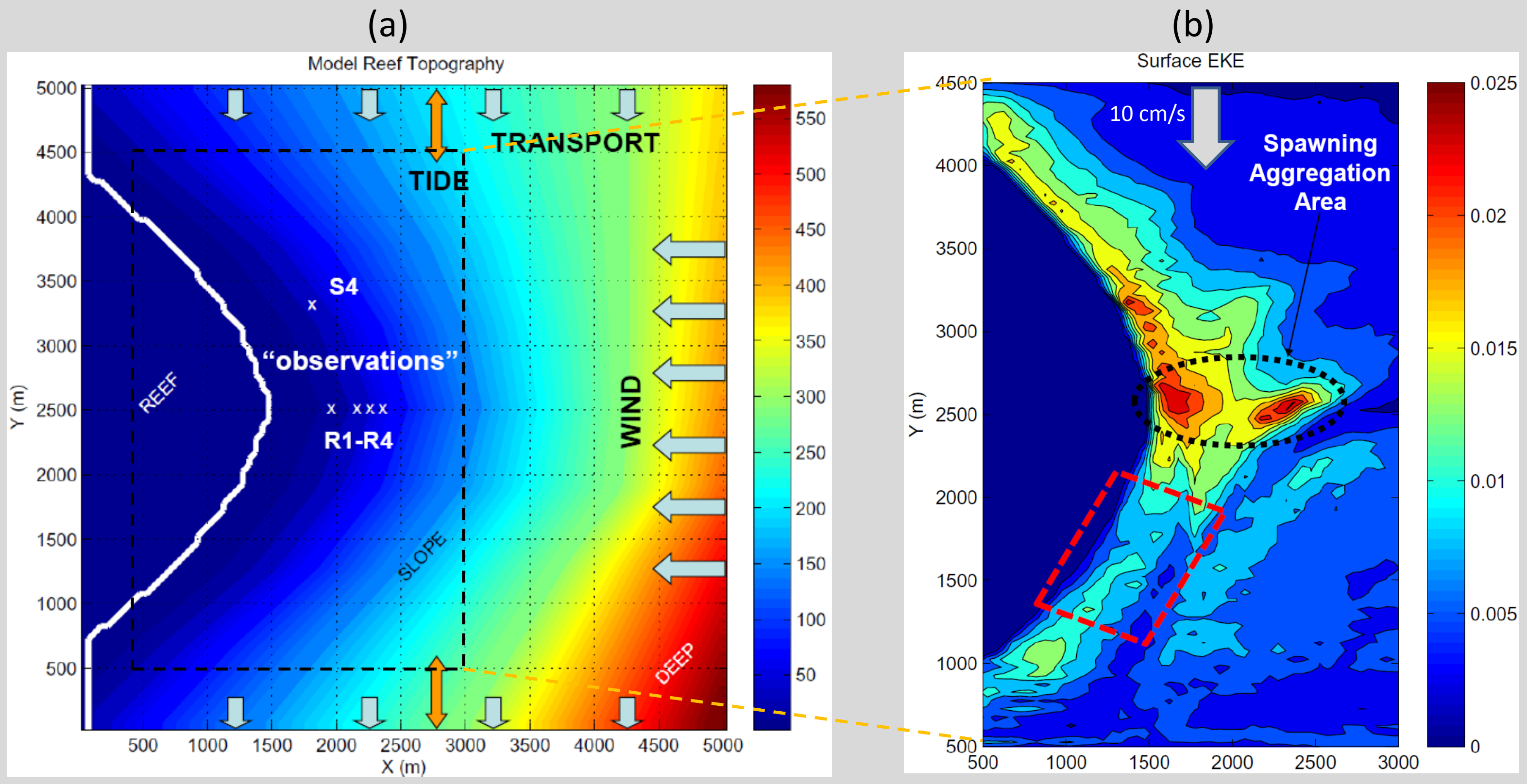


Fig. 1. Study area and observation locations (in c)

Numerical Model Simulations of Enhanced Mixing

- Model: The generalized coordinate version of the 3D Princeton Ocean Model (POM).
- Domain and Grid: 5km x 5km domain; **50m x 50m** horizontal grid size; 21 vertical sigma layers.
- Topography: idealized “reef-like” (Fig. 2) bathymetry in the west and 3 open boundary elsewhere.
- Forcing: tides; winds; transport representing coastal current and eddy influence.
- Experiments:
  - -Sensitivity of flow to forcing and generation of internal waves (Ezer et al., 2011)
  - - Simulations of a storm case in October 2009 (Ezer et al., 2012)



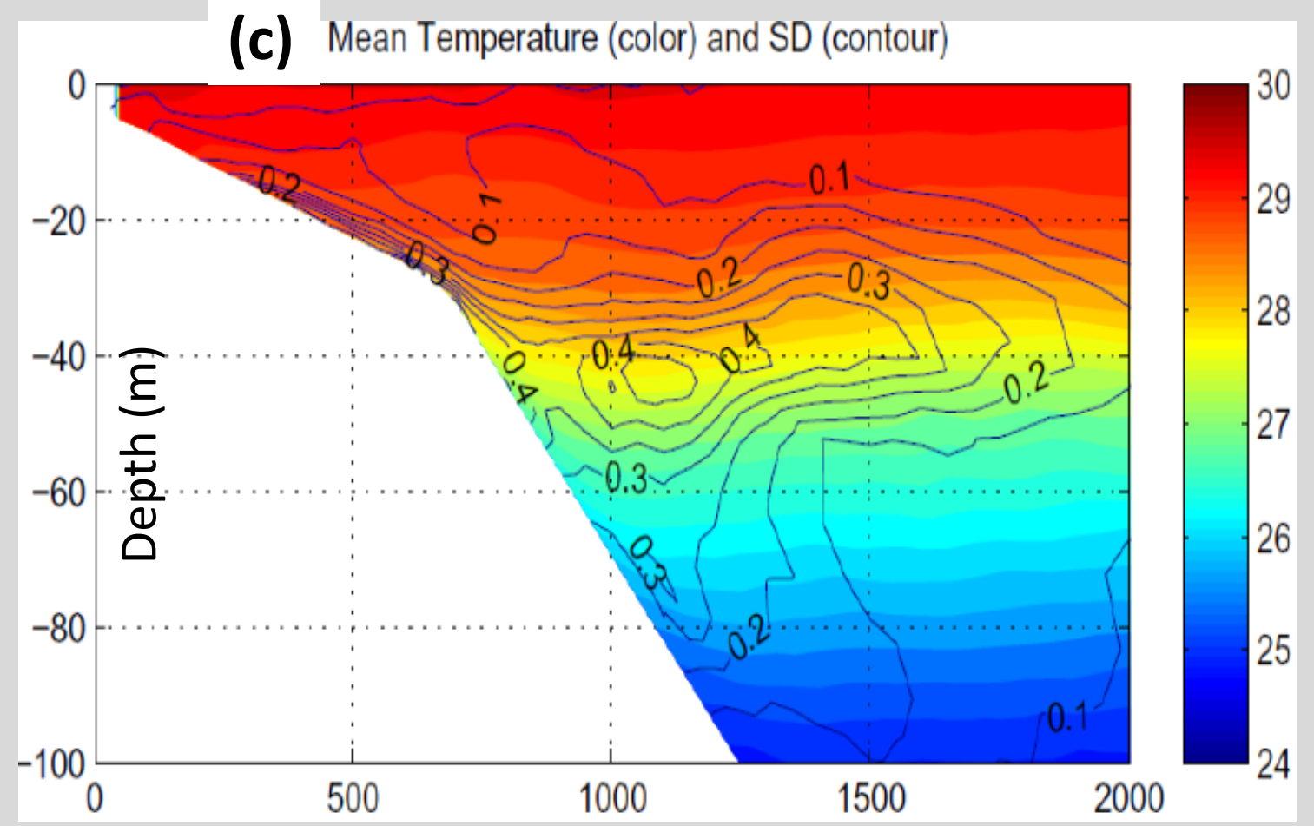


Fig.2 (a) The model topography (color; depth in m) and forcing. (b) Surface Eddy Kinetic Energy (m^2/s^2) when model forcing includes only 0.1 m/s flow from the north. (c) Mean temperature (color) and standard deviation (contour) across Y=2500m. Note that the highest variability (and mixing) is near the aggregation area (oval in b), while the larvae settlement area downstream (red box) is less energetic. Mixing is induced by bottom slope-internal wave interactions at the thermocline (c).

Observations of Internal Waves and Unusual Water Level

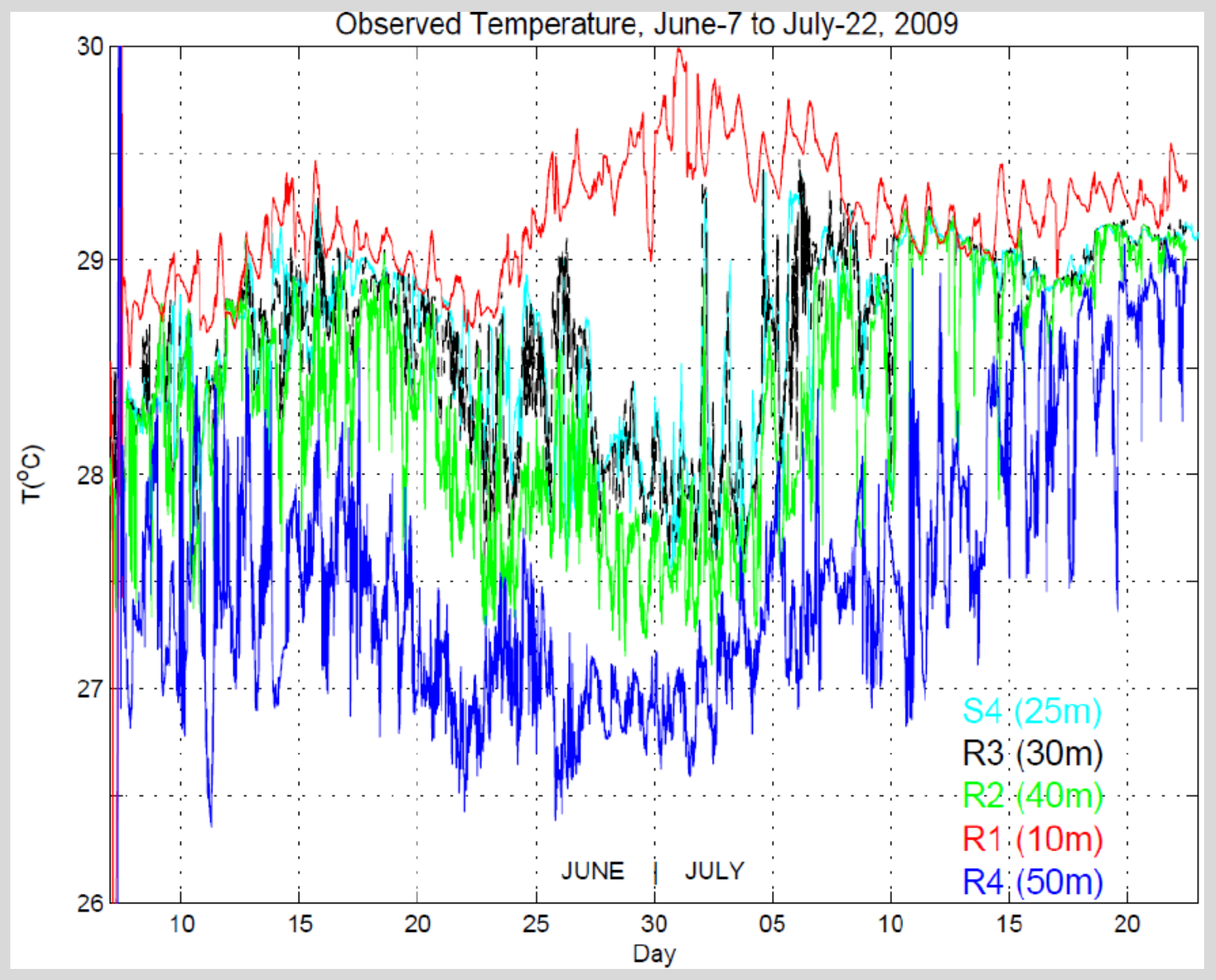


Fig. 3. Observed temperatures (see location in Fig. 1c) indicate internal waves (Ezer et al. 2011)

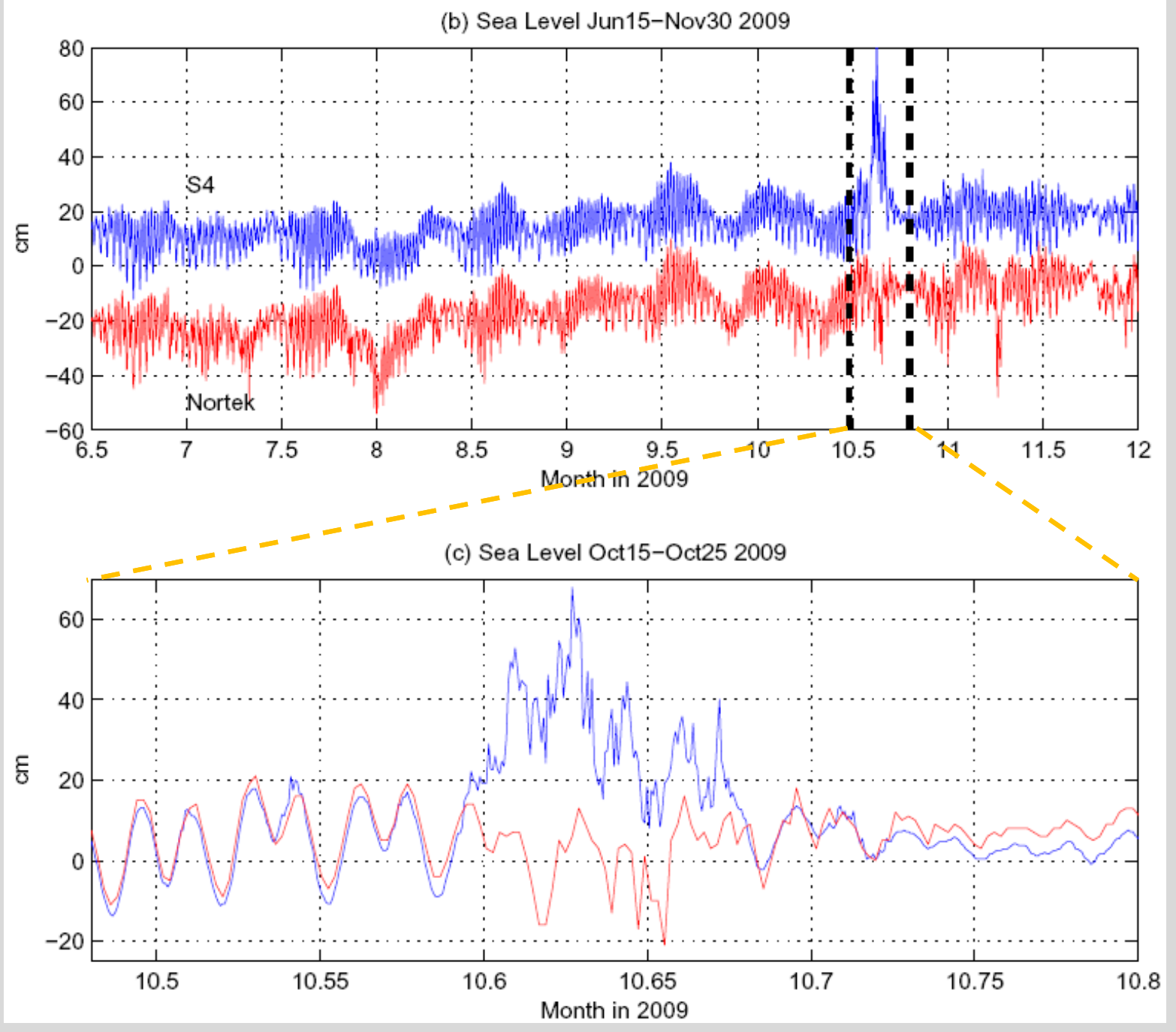


Fig.4. During a few days in October 2009, very unusual water levels were observed, a difference of **~70 cm elevation over ~2 km distance** can only be explained by non-linear small-scale flow-topography interactions and unusual strong flows.

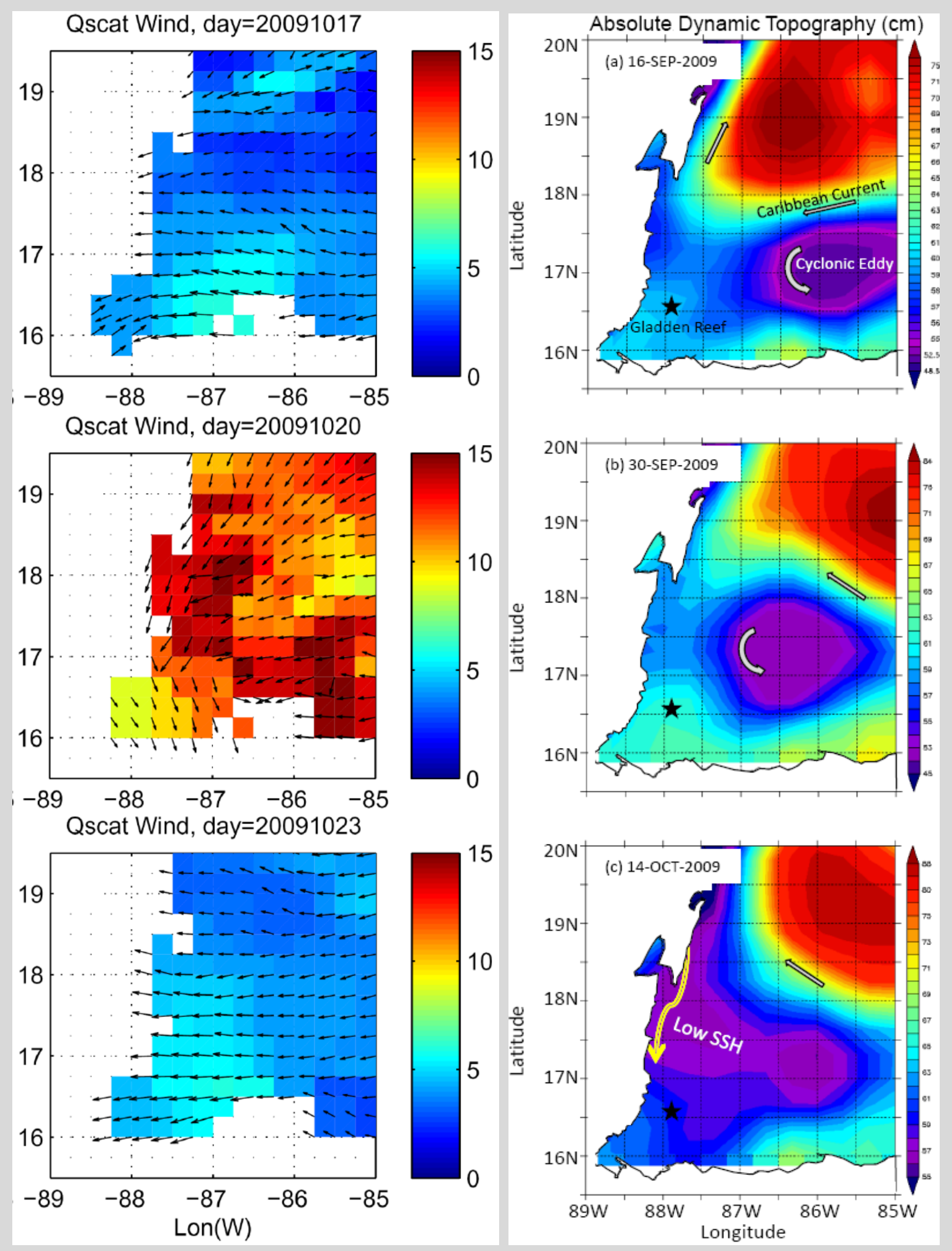
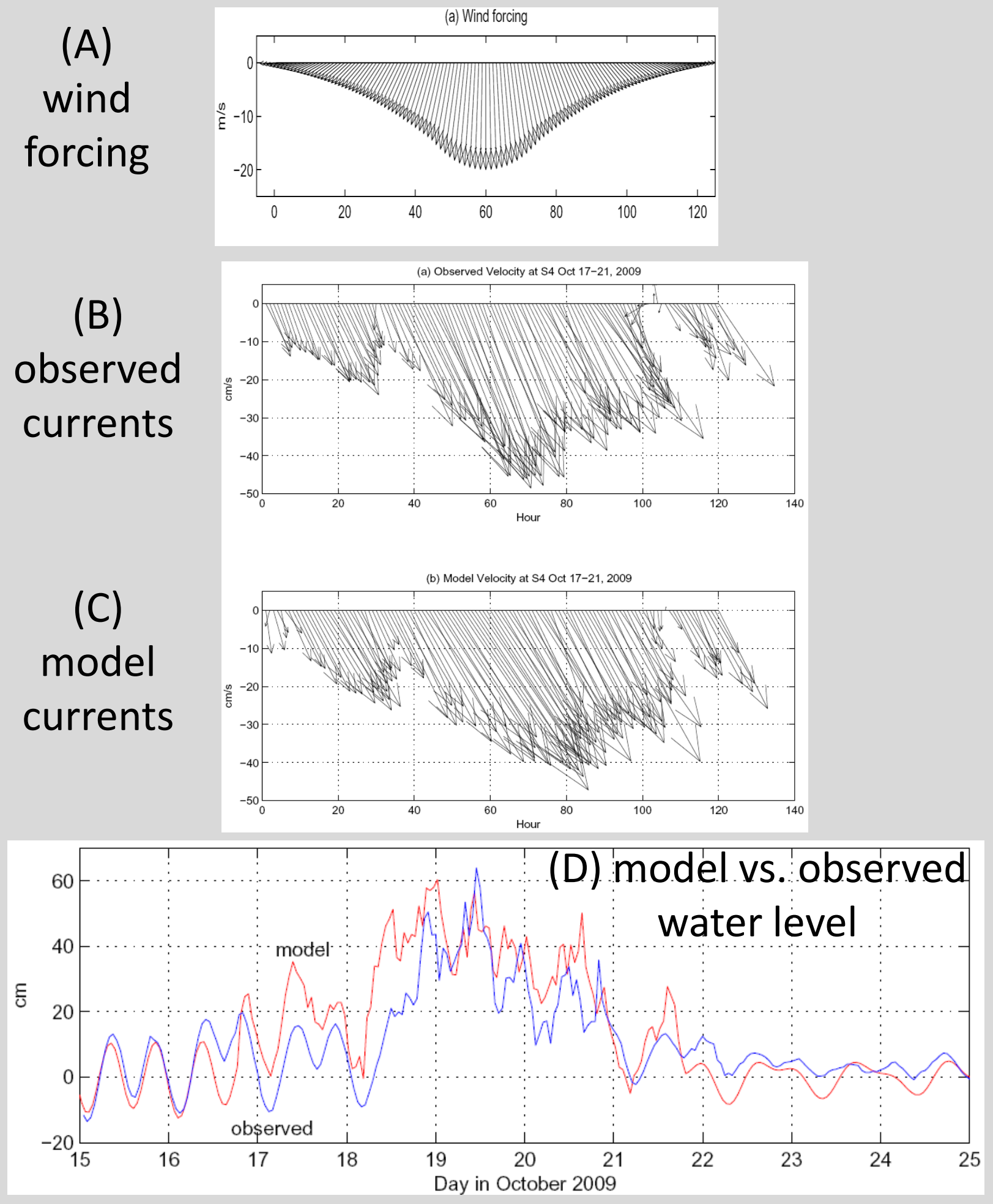


Fig.5. In mid October 2009A an unusual combination of a short-lived local storm (see QuickScat winds in left panels), and a cyclonic Caribbean eddy that propagated westward toward the shore (see Altimeter SSH in right panels) resulted in very strong (over 1 m/s) southward coastal flow near the reef. In addition, this period coincides with a transition from a spring to neap tide (Fig. 4).

Simulations of Storm-Induced Flows



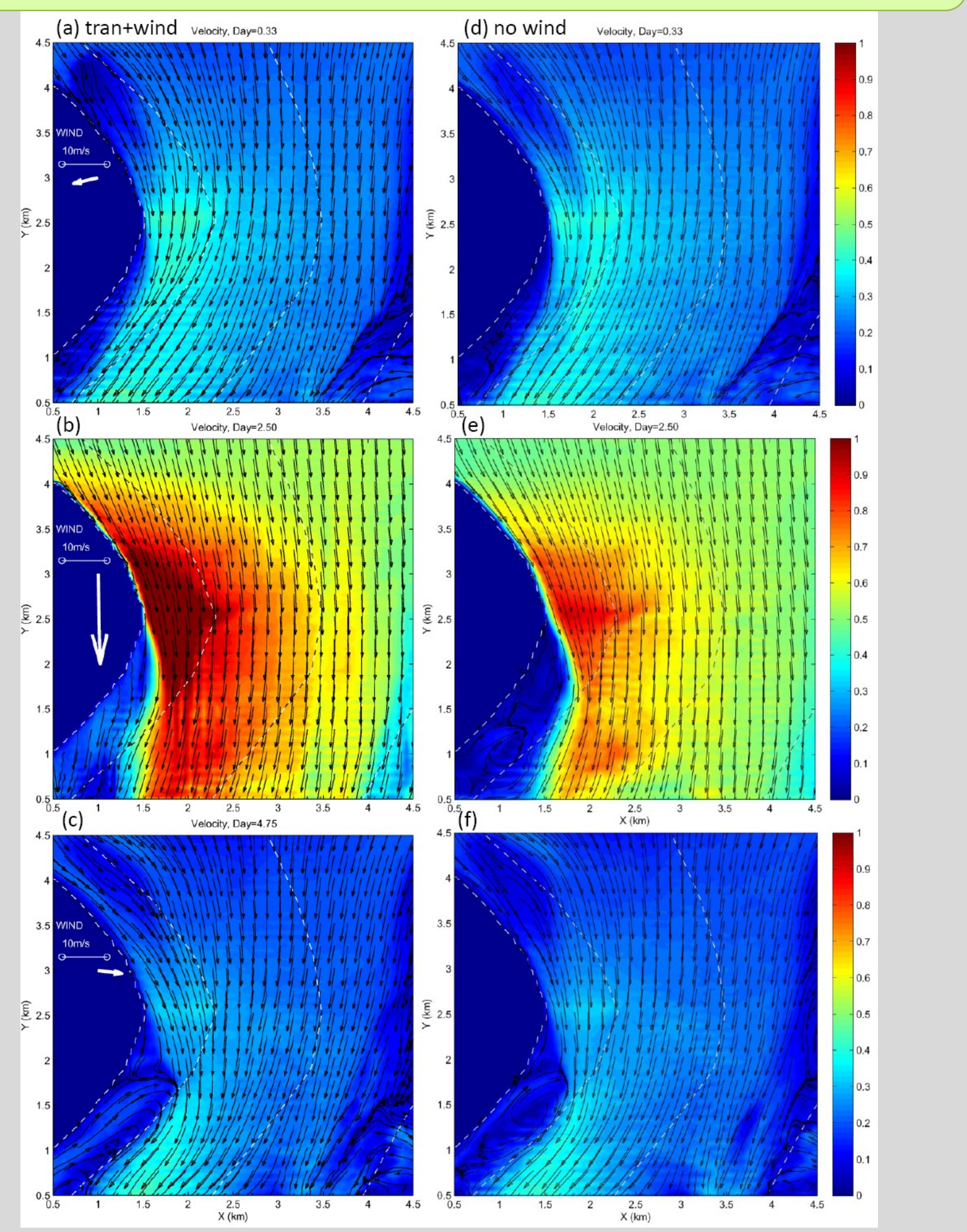


Fig.6. The October 2009 storm was simulated using idealized wind (A) and southward boundary flow on the model north boundary. Velocity (B &C) and water level (D) were simulated quite well. The variations in water level are attributed more to variations in the coastal current and tides and less to the direct wind effect (wind is not realistic in the model).

Fig.7. Simulated surface currents with wind (left) and without wind (right) show the intensification of the flow at the tip of the reef (where fish spawning aggregations occur). The influence of the wind is most pronounced in the recirculation gyre downstream of the reef; this gyre may be important for local retention of eggs and larvae.

Conclusions

1. The unique shape of reefs that different species of Caribbean fish choose as spawning aggregation sites suggest survival advantages associated with small-scale flow-topography interactions.
2. Idealized high-resolution numerical model and observations show intense mixing at the tip of the reef due to internal waves interacting with steep slopes; this mixing may help spread the eggs and larvae and reduce predation.
3. Recirculation gyres in the lee side of the reef may help local retention of the eggs and larvae in a more protected area of the reef.
4. Simulations of an unusual storm case show non-linear dynamics that are different than classical storm surges, whereas along-shore coastal currents are amplified over small distances of hundreds of meters to a few kilometers.
5. Multi-disciplinary/multi-scale modeling approaches are thus needed.

References

Ezer T, Thattai DV, Kjerfve B, Heyman WD (2005) On the variability of the flow along the Meso-American Barrier Reef system: a numerical model study of the influence of the Caribbean current and eddies. Ocean Dyn 55:458-475.

Ezer T, Heyman WD, Houser C, Kjerfve B (2011) Modeling and observations of high-frequency flow variability and internal waves at a Caribbean reef spawning aggregation site. Ocean Dyn 61(5):581-598.

Ezer T, Heyman WD, Houser C, Kjerfve B (2012) Extreme flows and unusual water levels near a Caribbean coral reef: was this a case of a “perfect storm”?. Ocean Dyn, submitted.

Heyman WD, Ecochard JB, Biasi FB (2007) Low-Cost Bathymetric Mapping for Tropical Marine Conservation: A Focus on Reef Fish Spawning Aggregation Sites. Mar Geodesy 30(1):37-50.

Heyman WD, Kjerfve B (2008) Characterization of transient multi-species reef fish spawning aggregations at Gladden Spit, Belize. Bull Mar Sci 83(3):531-551

Heyman WD, Kjerfve B, Ezer T (2008) Mesoamerican reef spawning aggregations help maintain fish population: A review of connectivity research and priorities for science and management, pp. 150-169. Marine Sanctuaries Conservation Series ONMS-08-07, NOAA, Silver Spring, MD